

**Investment in Hospital Care
Technology under Different
Purchasing Rules:
A Real Option Approach**

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Investment in Hospital Care Technology under Different Purchasing Rules: A Real Option Approach

Summary

In this article, we analyse the optimal investment decision in a new health care technology of a representative hospital that maximises its surplus in an uncertain environment. The new technology allows the hospital to increase the quality level of the care provided, but the investment is irreversible. The article uses the framework of the real option literature to show how the purchasing rules might influence the level of investment. We show that the investment in new technology is best incentivate within a long term contract where the number of treatments reimbursed depends on the level of investment made in the period when the technology is new. In this way, asymmetry of information does not affect the outcome of the contract. In our model in fact the purchaser can verify the level of the investment only at the end of each period but the purchasing rule has an anticipating effect on the decision to invest.

Keywords: Health care technologies, Medical quality, Irreversible investments, Real options

JEL Classification: I11, I18

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1 Introduction

The design of contracts for health care is not straightforward due to the peculiar characteristics of the product sold on this market which are well known and will not be recalled here.

The quality of the care provided is one of the main issues because this element, so important in determining the rate and speed of recovery of the patients and the cost of the service is usually non-observable. The health gain of each patient treated depends on the appropriateness of the treatment, on the technology used, on the effort of the medical staff and on some characteristics of the patient that are non observable. Even when quality is observable, it would anyway be non contractible because the clause would not be enforceable.¹

Following Chalkley and Malcomson (2000), quality can be defined as a multivariable vector that includes all the aspects of medical care such as appropriateness of the treatment, the investment in technology that benefit to the recipients and other aspects that are not strictly medical, but that can improve hospital's stay. They are services such as the number of beds per room, hours of visits, private telephones, nurses per ward, etc.

The literature so far has pointed out the existence of a trade off between the cost of the service, its quality, the ownership of the hospital and the level of enforcement of the contract (Chalkley and Malcomson, 1998, 2000 and 2002; Levaggi 2003a,b). Several models have been developed to show the effects on the contract of uncertainty and asymmetry of information (Levaggi, 1996, Chalkley and Malcomson, 1998 and 2000, Ma, 1994, Ellis, 1997). The common feature of these models is to assume that quality is a running, unverifiable cost, usually private information to the provider.

It is for this reason that most of the literature on contract setting in health care points towards enhancing the level of competition to reduce market power of the provider (Gravelle, 1999; Levaggi and Rochaix, 2003). According to this point of view, the purchaser should shop around for the provider that allows him to get the service with the best trade off between cost and quality. Providers and patients competition would enhance the level of quality of the service provided. However, this system seems to work only for primary care. For hospital care Eintoven (2002) shows that the level of competition, even in a private market like the US is quite low while Kessler and McClellan (2000) show that competition might be socially wasteful.

¹For the definition of observable but nonverifiable variables in contract theory see e.g. Laffont and Martimort (2002).

The reason for this apparent failure might depend on the intrinsic characteristics of quality in hospital care. We argue that medical care is the main determinant of quality which is in turn the result of an investment decision in health care technology. Once the hospital has made a specific quality improving investment, the decision is irreversible, and the investment determines the quality level of the health care produced by that provider for the years to come. Our assumption is in line with the most recent literature on new technology assessment which point out that technological changes produced substantial improvement in prognosis for several ailments (Baker and Phibbs, 2002, Medtap, 2004)

This assumption shifts the focus of the incentive compatible contract from cost revelation to intertemporal investment decisions.

Bös and De Fraja (2000) share some of our assumptions: quality is assumed to be the result of an investment decision and it is irreversible. In that paper, however, the intertemporal setting is not developed the authors concentrate their analysis on the effects of non-contractability of quality.²

The intertemporal setting we develop allows us to capture another important feature of quality. Although the investment can be implemented at any different stage in the decision process, the technology is innovative only at the beginning (first period) of its life when learning costs are higher and future operating costs to run the technology are not known. In subsequent periods (second period) the technology is consolidated and the hospital that has invested in the first period produces a positive externality to the system. Most of the technological innovation in health care cannot be patented and the hospitals that invest in the second period can use the innovation at a lower cost. In this respect we model the investment in the first period as mixed good that produces private and public benefits.

Yet, the intertemporal setting allows us to follow the suggestion by Palmer and Smith (2000) to use a real option approach in health technology assessment and develops a full model in this direction.

On a formal level we develop a two-period partial equilibrium model *à la* Abel et al. (1996) where the hospital is allowed to expand its capacity by making an investment in health care technologies now or in the future. This option has a value if future uncertainty has a sufficiently large downside effect to make waiting a preferable action³. In this environment we study

²Bös and De Fraja (2000) show that the hold up problem that emerges in this case may be alleviated if the health authority arranges to purchase the service from other providers other than the hospital.

³By analogy to financial options, it would be optimal for the hospital to delay exercising its option and proceeds with the investment in quality due to the hope of gaining a higher

the relationship between investment in quality and purchasing rules. The principal findings of our paper can be summarised as follows:

- a) Hospitals make substantial investment in new technology only if they are offered long-term contracts (a two-period contract in our model); if this is not the case, the investment in quality will be minimum and its intertemporal allocation will mean that hospitals invest in a technology only when this is a mature, well established technique;
- b) The purchasing rule chosen for the long term contract determines the timing of the investment in health care. In our model we make the number of patients treated in the second period depend on the investment made in period one. This reduces (or cancels out) the option value to delay the investment decision. This result, that derives from the properties of the option models, has important policy implications as the investment in quality can usually be observed (hence verified) only *ex post*.⁴
- c) The link between past levels of quality and the number of treatments reimbursed usually makes hospital to increase future levels of quality, our model shows instead that current levels are also incentivated, and this result is very important since the investment is innovative only in the first period of its implementation.
- d) The adoption of the technology when it is new implies an higher cost for patient treated so that the purchaser faces a trade off between quality, technological content of the care provided and average cost of provision.

The paper will be organized as follows: in the next section the features of the model are presented, in section 3 the hospital's investment decision is presented; in section 4 we show how quality decision at time 1 vary with the purchasing rule and finally section 5 concludes the paper.

2 The model

The traditional literature that deals with contracts for hospital health care often assumes that quality is a variable cost which might be observable *ex*

payoff in the future as uncertainty is resolved.

⁴The introduction of protocols for the treatment of specific ailments allows to verify *ex post* the appropriateness of the care offered such as the guides issued by NICE and NCQA..

post, but often it is not contractible.⁵ We argue that this way to model quality might not reflect its actual nature.

Quality is a multidimensional vector that includes hotel and medical services. The first category defines activities that are not strictly medical, but that can improve hospital's stay. They are services such as the number of beds per room, hours of visits, private telephones, nurses per ward, etc. Medical activities improve the prognosis and the recovery process of each admission. They include the technology used to treat the patient, the appropriateness of the treatment offered and the motivation/effort of the medical staff in taking care of the patient.

Hotel-related quality can be modelled as a variable cost, but the medical dimension mainly derives from an investment decision. Both elements are extremely relevant to determine patient's utility, but in this paper we restrict our definition of quality to medical quality and we argue that this specific component depends on the investment in health technology made by the provider.⁶ The investment is specific, irreversible and determines the type of treatment that can be supplied to the patient.

In this environment it follows that the decision of the hospital about the level of quality to supply becomes an intertemporal decision and the type of contract set by the purchaser (whether a spot or a long term one) is the main variable that determines the quality level of the care to be provided.

The assumption that medical quality depends on an investment decision has several effects on the way to approach the problem:

- contracts for health care have to be set in an intertemporal dimension;
- the trade off between the investment in quality, contract duration and purchasing rule has to be made explicit.
- the intertemporal dimension of the contract makes the medical quality verifiable ex post.

The model deals with the investment choices of a representative hospital, in a two-period framework as a proxy of long-term contracts, that is confronted by a purchasing rule set up by the provider. In this paper we do not make any specific assumption about the objective of the purchaser which might alternatively be a profit maximizing insurance company, an HMO or a benevolent health authority that wants to maximize the welfare of the

⁵See Chalckley and Malcomson (1998, 2000)

⁶In other words we assume that the treatment offered to the patient is always appropriate given the technology the hospital.

patients through the supply of hospital care. We assume that the patient has a limited choice in access to medical care, i.e. he can be admitted only in the hospital that the purchaser has chosen.⁷

To simplify the analysis, it will be assumed that patients can be affected only by one ailment that requires a standard treatment. The production process is however uncertain due to productivity shocks deriving from personal characteristics of the patient or input prices. Health care is an input into a process that leads to recovery. The personal ability of each individual to take advantage of the treatment determines the quantity of resources to be used. The price of the treatment might also vary because of a change in the input prices, in the protocols or the guidelines set up for the treatment of a particular ailment.

By the above arguments we introduce the following simplifying assumptions:

1. A new technology for producing health care is available at time 1 and the hospital may decide the level of investment and its intertemporal distribution. The investment in the new technology determines the medical quality level so we use q for the level of investment and quality as well. The current investment in quality is private information to the hospital but the purchaser can verify it ex post.⁸
2. The number of patients needing treatment is independent of quality, but the purchaser reimburses the hospital for the treatment of a number of patients $x \geq 0$ which is fixed in the first period and may increase in the second period if the hospital expand its investment in medical quality. In other words, we assume that the health authority **commits** to link the number of patients to treat in the second period to the investment policy of the hospital using the following linear rule:

$$x_2(q_1, q_2) \equiv x + \gamma q_1 + \alpha(q_2 - q_1) \quad \text{with } \gamma, \alpha \geq 0 \text{ and } \gamma \geq \alpha \quad (1)$$

where x is a fixed parameter, q_1 and q_2 is the stock of quality in the first period and in the second period respectively, and α and γ represent the relative weight attached by the purchaser to the investment in

⁷This assumption can be justified on several grounds. In private health care systems the insurance company offers the patient a list of hospitals to be admitted. In a public health system the choice depends on the type of organisation, but it is usually limited (Docteur and Oxley, 2003)

⁸i.e. that the purchaser observes the hospital quality ex post and may verify it before a court (or a health regional office).

the two periods. If $\gamma = \alpha$ the purchaser rewards the investment in quality at a uniform rate; if $\gamma = 0$ the hospital can increase its activity level only if it invests in the second period; finally, if $\alpha = 0$, the number of patients treated in the second period depends only on the investment at time $t = 1$.

3. Once the investment in the new technology is undertaken it cannot be abandoned.⁹ Quality accumulation is given by $q_2 = q_1 + i_2$, where q_1 is the stock of quality invested in the first period, i_2 denotes investment in period 2 and depreciation is absent.
4. The hospital can invest in quality at unit cost r . In section 4.2 we deal with the more general case in which the investment cost at time 2 is lower than the investment cost at time 1, i.e. $r_2 < r_1$.
5. In addition to the investment cost, the hospital faces some operating costs in running the new technology. These operating costs differ from period to period due to our assumption about the nature of the investment decision. In the first period the investment in new technology has a multiplicative effect on the cost to produce health care. It comprises set-up costs such as learning cost and human capital formation. Because of the investment in the new technology such costs are directly related to the size of the investment q rather than the number of patients to be treated x . In the second period, the extra investment in the same technology causes an increase in the cost due to pure reputation through the rule (1).¹⁰ The operative costs in each period are given by:

$$C^t(x_t, q_t, \beta_t) \equiv \begin{cases} \theta(q_1)C^1(x, \beta_1) & \text{for } t = 1 \\ \begin{cases} C^2(x_2(q_1, q_2), \beta_2) & \forall q_2 \geq q_1 \quad \text{with } q_1 > 0 \\ \text{or} \\ C^2(x, \beta_2) & \forall q_2 \geq 0 \quad \text{with } q_1 = 0 \end{cases} & \text{for } t = 2 \end{cases} \quad (2)$$

⁹Besides irreversibility, this assumption avoids the need to consider such operating options for the hospital as reducing output or even shutting down, and thereby considering reducing variable costs. For further details see e.g. Dixit and Pindyck (1994).

¹⁰As an example we might think about introducing laser therapy to treat patients with a specific ailment. In the first period we will have to bear the cost of the equipment and the cost related to teaching the staff how to use the new technology. In the second period the purchase of another laser to treat the same ailment simply increases the cost due to the increase in the number of cases treated.

where $\beta \in \mathbb{R}$ is a parameter capturing productivity shocks as well as the cost of factors of production other than quality investment. We also add, $\theta(0) = 1$, $\theta'(q_1) > 0$, $\theta''(q_1) < 0$, with the regularity conditions $\lim_{q \rightarrow 0} \theta'(q) > 0$ and $\lim_{q \rightarrow \infty} \theta'(q) = 0$. We complete the properties of the cost function assuming that is increasing and convex in the number of patients $C_{x_t}^t, C_{x_t x_t}^t > 0$, for $t = 1, 2$ and we make the following assumption on the costs of the hospital at $t = 2$:¹¹

$$C_{x_2 x_2 \beta}^2 > 0, \quad C_{x_2 x_2}^2 + x_2 C_{x_2 x_2 x_2}^2 < 0 \quad (3)$$

Yet, if $q_1 = 0$ the hospital may still invest in the new technology at time 2 but without reputation benefits, i.e. $C^2(x, \beta_2)$ for all q .

The cost function (2) allows the model to take account of another important characteristic that the investment in medical quality has in health care. This is the innovative content of the treatment offered. In the first period the technology is innovative and requires higher operating setting up costs which are in part a positive externality on the rest of the scientific community. In the second period the new technology has become established and by making its investment in this period the hospital gains from the positive externality and may have lower operative costs. Finally, without loss of generality, we assume in the paper that $C^1 = C^2 = C$.¹²

6. The hospital receives a payment per treatment p_t that is equal to the marginal cost $C_{x_t}^t(x_t, q_t, \beta_t)$, $t = 1, 2$ in exchange for the service delivered. The cost reimbursement scheme and the link (1) define our purchasing rule. The hospital's surplus function can be written as:

$$U^t(q_t, x_t, \beta_t) \equiv x_t p_t - C^t(x_t, q_t, \beta_t) = x_t C_{x_t}^t(x_t, q_t, \beta_t) - C^t(x_t, q_t, \beta_t) \quad t = 1, 2 \quad (4)$$

7. Finally, we introduce uncertainty in the model through the productivity shock β . We assume that β_1 is known and normalized to 1 while

¹¹Note that an increase in q_2 determines an increase of the marginal costs $C_{x_2 x_2}$, plus the reduction in the revenue obtained from the infra-marginal patients $x_2 C_{x_2 x_2 x_2}$. The condition (3) assures that the latter overweight the former. Such a assumption is consistent with even simple cost functions. For example let $C = (k - x)^{-\varepsilon}$ where ε and k are parameters. Then the above assumption is satisfied for a variety of parameter values including $\varepsilon = 2$ and $k/3 \leq x < k$.

¹²It is worth pointing out that the quality of results would not change if we assumed $C^1 \neq C^2$.

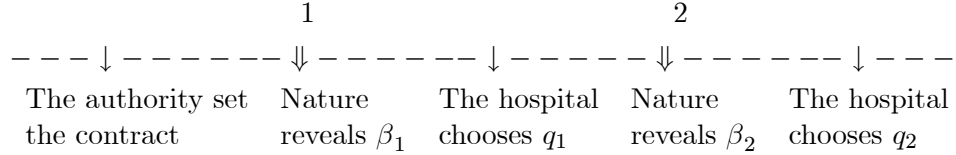
$\beta_2 \equiv \beta$ is stochastic and its realization is characterized by the cumulative distribution $\Phi(\beta)$ with density $\Phi'(\beta) > 0$ on $\beta \in [0, \infty)$, which is observed by the hospital and the purchaser.¹³

3 The hospital's investment decision

We consider the hospital's decision to investment in health care technology in a two-period framework *à la* Abel et al.(1996). If in period 1 the hospital makes an investment that it cannot resell in period 2 and future capital returns are uncertain, this investment decision involves the exercise of an option. Because of the uncertainty, the opportunity to wait to learn more about the future hospital's productivity level has a timing premium or holding value.

The role of β deserves some further explanations. The productivity shock can be observed by the hospital only at the beginning of each period and becomes public information. Given the marginal cost pricing rule we have assumed, the hospital bear no risk on the running cost. However, since q_2 depends on β_2 also q_1 is affected by its realization and in this respect it introduces uncertainty in our model.

The timing of the model can be summarized as follows. At the beginning of period 1, the health authority announces x , the number of patients to treat in the first period and the purchasing rule for the second period. The hospital, knowing β_1 and the purchasing rule, decides q_1 . At the beginning of period 2, q_1 becomes verifiable, nature reveals β_2 and, conditional on q_1 , the hospital chooses q_2 .



We start by describing the hospital's action in the second period, given the stock of quality q_1 inherited from period 1. We then step back and show how the marginal profitability in the first period depends on the hospital's expected action in the second period.

¹³As in Bös and De Fraja (2000), we assume that there is symmetry of information about the technology.

3.1 Second period

By assumptions 2, 5 and 6, the hospital's surplus at time 2 can be written as:

$$U^2(q_2, q_1, x, \beta) \equiv x_2(q_1, q_2)C_{x_2}(x_2(q_1, q_2), \beta) - C(x_2(q_1, q_2), \beta)$$

yet the same assumptions guarantee that $U_{q_2}^2(q_2, q_1, x, \beta) \geq 0$ is continuous and strictly decreasing in q and continuous and strictly increasing in β (see Appendix A). Then, for a given stock of q_1 inherited from period 1, we can define a critical values of β :¹⁴

$$U_{q_2}^2(q_1, x, \beta^*) \equiv \alpha(x + \gamma q_1)C_{x_2 x_2}(x + \gamma q_1, \beta^*) = r \quad (5)$$

At the beginning of period 2, nature reveals β and the hospital will adjust its stock of medical quality to the new optimal level that we identify as $q_2(\beta)$. The stock of quality must satisfy the constraint:

$$q_2(\beta) \geq q_1 \quad (6)$$

Thus, depending on the inherited stock q_1 , from (5) we obtain that when $\beta > \beta^*(q_1, \alpha)$ it is optimal for the hospital to invest in extra quality up to the point where the marginal return from quality equals the marginal investment cost (purchasing price) r . On the other hand, when $\beta < \beta^*(q_1, \alpha)$ the profitability is so low that the firm finds it convenient not to invest, so $q_2(\beta) = q_1$. Finally, by (2), if $q_1 = 0$ the surplus of the hospital at time 2 is always constant and then $q_2(\beta) = 0$ for all values of β .

3.2 First period

From (4) and (16), the following Lemma holds:

¹⁴By assumptions 4 and 5 we get:

$$\frac{\partial \beta^*}{\partial r} = \frac{1}{\alpha(x + \gamma q_1)C_{x_2 x_2 \beta}} > 0$$

and

$$\frac{\partial \beta^*}{\partial q_1} = -\frac{\alpha^2[C_{x_2 x_2} + (x + \gamma q_1)C_{x_2 x_2 x_2}]}{\alpha(x + \gamma q_1)C_{x_2 x_2 \beta}} > 0$$

Lemma 1 *The value of the hospital's investment in medical quality, defined as the expected present value of net cash flow accruing to the hospital when the stock of quality in period 1 is q_1 , is given by the following expression:*

$$\begin{aligned}
V(q_1, x) \equiv & \theta(q_1)[xC_x(x) - C(x)] \\
& + \delta \left\{ \int_0^{\beta^*} [(x + \gamma q_1)C_{x_2}((x + \gamma q_1), \beta) - C((x + \gamma q_1), \beta)] d\Phi(\beta) \right. \\
& + \int_{\beta^*}^{+\infty} \{ [(x + \gamma q_1 + \alpha(q_2(\beta) - q_1))C_{x_2}((x + \gamma q_1 + \alpha(q_2(\beta) - q_1)), \beta) \\
& \quad \left. - C((x + \gamma q_1 + \alpha(q_2(\beta) - q_1)), \beta)] - r[q_2(\beta) - q_1] \} d\Phi(\beta) \}
\end{aligned} \tag{7}$$

where δ is the discount factor.

Proof. See Appendix A ■

Hence, the first period decision problem is simply given by:

$$q_1 = \arg \max [V(q_1, x) - rq_1]. \tag{8}$$

The first order condition for a maximum yields:

$$\begin{aligned}
V_{q_1}(q_1, x) \equiv & \theta'(q_1)[xC_x(x) - C(x)] + \delta \left\{ \int_0^{\beta^*} \gamma(x + \gamma q_1)C_{x_2x_2}((x + \gamma q_1), \beta) d\Phi(\beta) \right. \\
& \left. + \int_{\beta^*}^{+\infty} \gamma(x + \gamma q_1 + \alpha(q_2(\beta) - q_1))C_{x_2x_2}((x + \gamma q_1 + \alpha(q_2(\beta) - q_1)), \beta) d\Phi(\beta) \right\} = r.
\end{aligned} \tag{9}$$

Defining $q_1^{s.t.}$ the stock of medical quality that the hospital would purchase in a short-term contract (i.e. $U_{q_1}^1(q_1^{s.t.}, x) \equiv \theta'(q_1^{s.t.})[xC_x(x) - C(x)] = r$), we can write the following proposition:

Proposition 1 *A long-term contract increases the investment in period 1:*

$$V_{q_1}(q_1, x) > U_{q_1}^1(q_1, x) \quad \Rightarrow \quad q_1 > q_1^{s.t.}$$

Proof. See Appendix B ■

This result has important policy implications: in order to increase the level of investment in new health technology, a long term contract has to be set. The long term arrangement is a reward the hospital receives for the positive externality created by the use of the new technology at an early stage. This creates a trade off between competition and incentives to invest in new technology. Competition is enhanced by short run agreements that allow the purchaser to choose each period the provider offering the lowest price. However, if quality depends on an irreversible investment decision, this policy would lead to low quality level. This might be the reason why competition in the health care market is not as high as one might expect (Eintoven, 2002; 2004). This result is in line with the recent literature that suggests that the use of long term contracts reduces the hold up problem (Chalkley and Malcomson, 2000; Chung, 1991; Aghion et al., 1994).

Furthermore, since q_1 and hence $\beta^*(q_1, \alpha)$ are ex post verifiable, the first order condition (9) is also consistent with the assumption of nonverifiability of the quality at time 2. This property comes from the application of the principle of optimality of the dynamic programming. The optimality principle says that an optimal quality-path has the property that, given the initial conditions and control values over an initial period, the control over the remaining periods must be optimal for the remaining problem, with the state variable resulting from the early decisions considered in the initial condition (Dixit, 1990, pp. 164-166). Formally this implies finding a state contingent function $q_2(\beta)$ such that the hospital chooses the quality at time 1 by equating $V_{q_1}(q_1, x)$ to r . Suppose now that the hospital, expecting to report at $t = 2$ a higher value of investment, chooses at time 1 $\tilde{q}_2(\beta)$, with $\tilde{q}_2(\beta) > q_2(\beta)$ for all $\beta > \beta^*$. This cannot be an optimal decision. In fact, since $V_{q_1\tilde{q}_2}(q_1, x) < 0$, the hospital can do better by choosing $\tilde{q}_2(\beta) = q_2(\beta)$: the profit flow that the firm expects to obtain following the policy $q_2(\beta)$ is the best that it can do, at least till $t = 2$.¹⁵

¹⁵In addition, since at time 2 the purchaser observes and verifies q_1 (β^*), it is always able to infer $q_2(\beta)$ directly from (9) (i.e. $q_2(\beta)$ is uniquely determined by $U_{q_2}^2(q_2(\beta), q_1, x, \beta) = r$). This makes the second period a pure nonverifiability model, i.e. even though the revelation of β makes q_2 common knowledge between the purchaser and the provider, it cannot be enforced by a third party. To achieve the first best allocation a Nash implementation mechanism is needed. Laffont and Martimort (2002), for example, show that the simple incentive compatible contracts used in the adverse selection context with ex ante contracting, perform quite well in the case of nonverifiability and risk neutrality of the hospital. This is, however, beyond the scope of this paper.

3.3 Analysis of some special cases

A long term contract can be written in several ways. In our approach we have used the following rule:

$$x_2(q_1, q_2) = x + \gamma q_1 + \alpha(q_2 - q_1) \quad \text{with } \gamma, \alpha \geq 0 \text{ and } \gamma \geq \alpha$$

There are three cases which is instructive to examine. First, if $\gamma = \alpha$ the purchasing rule becomes $x_2 = x + \alpha q_2$. According to the condition $U_{q_2}^2(q_2(\beta), q_1, x, \beta) = r$ the necessary condition for a maximum (9) becomes:

$$\begin{aligned} & V_{q_1}(q_1, x; \gamma = \alpha) \\ \equiv & \theta'(q_1)[xC_x(x) - C(x)] + \delta \left\{ \int_0^{\beta^*} \alpha(x + \alpha q_1) C_{x_2 x_2}((x + \alpha q_1), \beta) d\Phi(\beta) \right. \\ & \left. + r(1 - \Phi(\beta^*)) \right\} \\ \equiv & \theta'(q_1)[xC_x(x) - C(x)] + \delta \left\{ \int_0^{+\infty} \alpha(x + \alpha q_1) C_{x_2 x_2}((x + \alpha q_1), \beta) d\Phi(\beta) \right. \\ & \left. - \int_{\beta^*}^{+\infty} [\alpha(x + \alpha q_1) C_{x_2 x_2}((x + \alpha q_1), \beta) - r] d\Phi(\beta) \right\} = r \end{aligned}$$

where β^* is given by (5) under $\gamma = \alpha$.

Second, if $\gamma = 0$ the purchasing rule becomes $x_2 = x + \alpha(q_2 - q_1)$, which makes the surplus $U^2(x, \beta)$ independent from q at $q_2 = q_1$. The hospital's investment in the second period i_2 no longer depends on q_1 . Thus, the condition (9) simply reduces to a static optimization:

$$V_{q_1}(q_1, x; \gamma = 0) \equiv \theta'(q_1)[xC_x(x) - C(x)] = r. \quad (11)$$

Third, if $\alpha = 0$ the purchasing rule reduces to $x_2 = x + \gamma q_1$. In this case, for any given stock of q_1 inherited from period 1, the surplus at $t = 2$ is always constant, which makes $q_2(\beta) = q_1$ for all β . Then, condition (9) becomes:

$$V_{q_1}(q_1, x; \alpha = 0)$$

$$\equiv \theta'(q_1)[xC_x(x) - C(x)] + \delta \left\{ \int_0^{+\infty} \gamma(x + \gamma q_1) C_{x_2 x_2}((x + \gamma q_1), \beta) d\Phi(\beta) \right\} = r \quad (12)$$

Finally, as by assumption 5, $U_{q_1}^1(q_1, x) \geq 0$ is continuous and strictly decreasing in q with $\lim_{q_1 \rightarrow \infty} U_{q_1}^1(q_1, x) = 0$, we may conclude this section noting that $q_1^{s.t.}$ is strictly positive, which implies also that:

Corollary 1 q_1 and $q_2 \geq q_1$ are strictly positive.

Proof. Straightforward from proposition 1. ■

4 Analysis of the results and policy implications

4.1 The trade off between investment and purchasing rule

We begin analyzing the effect of a change in the rule that links the number of patients to treat to the investment in quality by comparing the three cases presented above. For better understanding of the role played by the purchasing rule on the hospital's investment decision, let us use the option decomposition of (7) proposed by Abel et al.(1996). That is:

Lemma 2 *The value of the hospital's investment can be written as:*

$$V(q_1, x) = G(q_1, x) - \delta O(q_1, x) \quad (13)$$

where:

$$G(q_1, x) \equiv \theta(q_1)[xC_x(x) - C(x)] + \delta \int_0^{+\infty} [(x + \gamma q_1) C_{x_2}((x + \gamma q_1), \beta) - C((x + \gamma q_1), \beta)] d\Phi(\beta)$$

$$O(q_1, x) \equiv$$

$$\begin{aligned}
& \int_{\beta^*}^{+\infty} \{ - [(x_2(q_1, q_2(\beta)))C_{x_2}(x_2(q_1, q_2(\beta)), \beta) - C(x_2(q_1, q_2(\beta)), \beta)) - rq_2(\beta)] \\
& + [((x + \gamma q_1)C_{x_2}((x + \gamma q_1), \beta) - C((x + \gamma q_1), \beta)) - rq_1] \} d\Phi(\beta)
\end{aligned}$$

Proof. See Appendix C ■

The term $G(q_1, x)$ is the hospital's expected present value of returns during the contract keeping the stock of medical quality fixed at q_1 . This can be interpreted as the hospital's value when it does not expand its investment in the second period. The term $O(q_1, x)$ indicates the value of the (*call*) option to expand in the second period if profitability rises above β^* . Equation (13) has then an interesting and immediate interpretation: when the hospital invests in period 1 it gets the value $G(q_1, x)$ but gives up the opportunity or option to invest in the future, valued at $O(q_1, x)$.

Similarly as in (9), the optimal amount of quality in period 1, depends on a comparison between marginal benefits and marginal costs:

$$G_{q_1}(q_1, x) = r + \delta O_{q_1}(q_1, x) \quad (14)$$

where:

$$\begin{aligned}
G_{q_1}(q_1, x) &\equiv \theta'(q_1)[xC_x(x) - C(x)] + \delta \int_0^{+\infty} \gamma(x + \gamma q_1)C_{x_2x_2}((x + \gamma q_1), \beta)d\Phi(\beta) \\
O_{q_1}(q_1, x) &\equiv \int_{\beta^*}^{+\infty} \frac{\gamma}{\alpha} [\alpha(x + \gamma q_1)C_{x_2x_2}((x + \gamma q_1), \beta) - r]d\Phi(\beta) \geq 0
\end{aligned}$$

Equation (14) emphasizes the role played by the option pricing approach in determining the optimal stock of investment in period 1. The hospital's optimal behaviour does not simply equalize the expected present value of marginal returns in the first period ($G_{q_1}(q_1, x)$) and the marginal cost of the investment r . Costs are represented by the purchase price of the investment, r , plus the value of the marginal call option, $O_{q_1}(q_1, x)$, as investing in period 1 gives up the opportunity to delay the investment.

Defining $q_1(\gamma = \alpha)$, $q_1(\gamma = 0)$ and $q_1(\alpha = 0)$ the stock of quality that the hospital would install under the three cases examined in the previous section, we can prove the following proposition:

Proposition 2 *The investment in period 1 can be ranked as follows:*

$$q_1(\gamma = 0) = q_1^{s.r.} < q_1(\gamma = \alpha) < q_1(\alpha = 0)$$

Proof. See Appendix D ■

The last proposition can be interpreted as follows: the policy of incentivizing the investment in the technology only when it is no longer new ($\gamma = 0$) gets the same result as a short run contract which, being more flexible should then be preferred. A uniform incentive in investing in quality ($\gamma = \alpha$) gives a better incentive than a short term contract, but the most effective policy is perfect discrimination ($\alpha = 0$): the last rules in fact implies that the hospital has the maximum incentive to invest in quality when the purchasing rule implies that only the investment made in the first period enters in the decision of the number of patients to send to a specific hospital. That is, setting $\alpha = 0$ washes out the option value of delay held by the hospital.¹⁶

In the latter case the purchaser gives in fact a sort of patent to the hospital that has first invested in the new technology. The number of patients that can be treated depends in fact only on the level of investment made in the first period and those who will invest in later periods will not see any increase in the number of case they might treat.

This result has important policy implications: even if the level of investment can be observed ex post, asymmetry of information can be ruled out of the system. When the contract is signed, the purchaser cannot observe the level of investment in health technology, but he will be able to do so before implementing the relevant part of the contract. In our model this is a sufficient deterrent not to cheat on the level of investment in the first period. In the second period the issue becomes irrelevant since the new investment is not considered in the decision of how many patients to send to a specific hospital.

Finally, we further investigate the effect of a change in the purchasing rule by totally differentiating the first order condition (9) with respect to α :

$$\frac{dq_1}{d\alpha} = -\frac{V_{q_1\alpha}(q_1, x)}{V_{q_1q_1}(q_1, x)} \quad (15)$$

This expression must be evaluated at the maximum of the hospital's investment choice, that is at the point in which $V_{q_1}(q_1, x) - r = 0$. Since at

¹⁶It is also worth noting that the extreme result of zero investment in the second period when $\alpha = 0$ is only due to our two-period horizon setting.

this point $V_{q_1 q_1}(q_1, x) < 0$ by the second order condition, the sign of (15) is driven by the numerator:

$$V_{q_1 \alpha}(q_1, x) \equiv \delta \int_{\beta^*}^{+\infty} \{\gamma(q_2(\beta) - q_1) [C_{x_2 x_2} + (x + \gamma q_1 + \alpha(q_2(\beta) - q_1)) C_{x_2 x_2 x_2}] +$$

$$\gamma \alpha [C_{x_2 x_2} + (x + \gamma q_1 + \alpha(q_2(\beta) - q_1)) C_{x_2 x_2 x_2}] \frac{\partial q_2(\beta)}{\partial \alpha} \} d\Phi(\beta) < 0$$

As $\frac{\partial q_2(\beta)}{\partial \alpha}$ is generally positive, the slope of the relationships between q_1 and α turns out to be negative, i.e. $\frac{dq_1}{d\alpha} < 0$.¹⁷ Then, by continuity, for a given value of the parameter γ , any increases of the number of patients driven by the investment in quality in the second period reduces investment in the first period over the range $(q_1(\gamma = \alpha), q_1(\alpha = 0))$.

4.2 The trade off between quality and investment cost

So far we have assumed that $r_2 = r_1 = r$. However the cost of many health care technologies face a decreasing cost as time goes by. A good example is MR scanners whose cost for a fixed technological level is decreasing through time. This can be done by simply assuming that $r_2 = (1 - \mu)r$ with $0 < \mu < 1$ and substituting it into the equation (14). Direct inspection shows that μ affects only the option value:

$$O_{q_1}(q_1, x) \equiv \int_{\beta^*}^{+\infty} \frac{\gamma}{\alpha} [\alpha(x + \gamma q_1) C_{x_2 x_2}((x + \gamma q_1), \beta) - (1 - \mu)r] d\Phi(\beta) \geq 0$$

where β^* is evaluated by (5) taking account of the lower cost $(1 - \mu)r$. The derivative of O_{q_1} with respect to μ gives:

¹⁷To be precise, for any given $\beta > \beta^*$ the optimal investment at $t = 2$ requires:

$$U_{q_2}^2(q_2, x, \beta) \equiv \alpha x_2(q_1, q_2) C_{x_2 x_2}^2(x_2(q_1, q_2), \beta) = r, \quad (16)$$

from which we may show that:

$$\frac{\partial q_2}{\partial \alpha} = - \frac{x_2(q_1, q_2) C_{x_2 x_2}^2 + \alpha(q_2 - q_1) [C_{x_2 x_2}^2 + x_2(q_1, q_2) C_{x_2 x_2 x_2}^2]}{U_{q_2 q_2}^2(q_2, x, \beta)} \quad (17)$$

As it is evident the sign of (17) is generally positive except for value of α close to γ where it may turns negative.

$$\frac{\partial O_{q_1}(q_1, x)}{\partial \mu} = r(1 - \Phi(\beta^*)) - \frac{\gamma}{\alpha} [\alpha(x + \gamma q_1) C_{x_2 x_2}((x + \gamma q_1), \beta^*) - (1 - \mu)r] \frac{\partial \beta^*}{\partial \mu} < 0 \quad (18)$$

and, since $\frac{\partial \beta^*}{\partial \mu} < 0$, we may conclude (see figure):

Corollary 2 *The investment in period 1 decreases as the cost in period 2 decreases:*

$$\frac{dq_1}{d\mu} < 0$$

Except when $\alpha = 0$ where the effect is nil:

$$\frac{dq_1(\alpha = 0)}{d\mu} = 0$$

Proof. Straightforward from (14), (18) and proposition 2. ■

The second part of corollary follows from the fact that $\alpha = 0$ eliminates the option value to delay the investment by the hospital and for this reason there is no advantage in waiting to invest.

4.3 The trade off between price and quality

Finally in this section we show the trade off that exists between the price for health care and its technological content. We focus on the cost for health care in the first period when the technology is new. If the purchaser does not want to commit itself to a long term contract in order to increase the level of competition in health care, it will get a minimum quality level and a correlated cost equal to:

$$p_1^{s.r.} = C_x(x, q_1^{s.r.}) \equiv \theta(q_1^{s.r.}) C_x(x)$$

Bös and De Fraja (2000) and Chalkley and Malcomson (1998) suggest to improve on this contract by making the number of patients treated depend on the level of the quality offered by the hospital in the first period. Then:

$$p_1 = C_x(x, q_1) \equiv \theta(q_1) C_x(x)$$

where q_1 is given by (9) As long as $q_1 > q_1^{s.r.}$ direct inspection gives $p_1 > p_1^{s.r.}$, and the positive relationship between quality and patient treated, shows that:

Corollary 3 *If the purchaser wants to make available to the community new technologies, the price for each treatment is higher:*

$$\frac{d(p_1/p_1^{s,r})}{d\alpha} < 0$$

Proof. Straightforward from proposition 2. ■

This shows the trade off between quality and the price for health care. The level of technological investment to be made will then depend on the willingness to pay of the community for innovation in health technology.

Furthermore, although our model deals only with a representative hospital, the above result may help to say something about the effect of competition on the investment decision: α can in fact be interpreted as a measure of intertemporal competition among hospitals. The result of corollary 2 is due to the combined effect of the incentive to invest in the first period and to the reduced level of competition in the second period. To show this, let us consider the case in which $\alpha = 0$. The hospitals that have invested in the technology at time 1 have a sort of monopoly power since all the competitors will not receive extra patients at time 2 for the specific technology even if they have invested in it. For $0 < \alpha < \gamma$, the technology is rewarded, but there is still a preference towards the hospitals that have invested in the first period. Finally, for $\alpha = \gamma$ there is no competitive advantage in period two since the investment in the specific technology is rewarded at the same rate, independently of its intertemporal distribution.¹⁸

5 Conclusions

This paper examines the relationship between purchasing rules and medical quality when quality depends on an irreversible investment decision. The level of investment is observable ex post while costs are subject to uncertainty. We concentrate on the response of a representative hospital to different purchasing rules set by the purchaser. The hospital is a surplus maximizing unit that has to take decision in a two period model in a context of uncertainty and asymmetry of information. Uncertainty has several dimensions that relates to the cost of provision and to the innovation process while asymmetry of information derives the observation of quality of health care only ex post.

¹⁸Note, however, that as long as q_2 is not verifiable, the hospitals may claim a higher q_2 to obtain a higher payment per treatment at $t = 2$, see footnote 15.

We define quality as an investment decision in health technology that produces in the first period of its application a positive externality. The investment is in fact assumed to be innovative only in the first period if its application when costs are higher due to the learning process. In the following period the hospital faces only set up and/or expanding costs.

We show that a trade off exists between the duration of the contract and quality. In particular a one period-short term contract is not effective in promoting investments in innovative technology, as one might expect.

The purchasing rule chosen is also very important. We show that the most effective incentive to invest in new technology is to make the number of patients to be treated by an hospital depend only on the level of investment in the first period.

In this case the purchaser gives a sort of patent to the hospital that has first invested in the new technology since those who will invest in later periods will not see any increase in the number of case they might treat. This patent is able to canceled out the hospital's option value to delay the investment. This policy can be applied only in a context where patients' choice is ruled out. If patients could choose where to go, the purchaser would not be able to control the flow of patients going to different hospitals and the incentive to invest might be reduced. This consideration opens up the discussion on another topical theme in health economics, i.e. patients' choice and its consequences on the system. From this analysis it seems that a trade off might exists between the level of investment and patients' choices, but these effects should be explored further.

Several other extension can be proposed. In our paper the purchaser does not play an active role: the further logical step in our analysis would be to define an objective function for the purchaser and to find the optimal contract in this environment. The effect of different pricing rules could also be studied. In our model we in fact assume that the provider is reimbursed using a marginal cost pricing rule, but in health care prospective, mixed and incentive compatible payment systems are also used.

A Proof of Lemma 1

Let first describe the properties of the hospital's surplus function (4). From (1), (2), (3) and (4), easy computation shows that at $t = 1$ we get:

$$U^1(q_1, x) \equiv \theta(q_1)[xC_x(x) - C(x)] > 0, \quad (19)$$

with the properties:

$$U_{q_1}^1(q_1, x) \equiv \theta'(q_1)[xC_x(x) - C(x)] > 0, \quad (20)$$

$$U_{q_1 q_1}^1(q_1, x) \equiv \theta''(q_1)[xC_x(x) - C(x)] < 0. \quad (21)$$

At $t = 2$, the hospital's surplus is:

$$U^2(q_2, q_1, x, \beta) \equiv x_2(q_1, q_2)C_{x_2}(x_2(q_1, q_2), \beta) - C(x_2(q_1, q_2), \beta), \quad (22)$$

with $x_2(q_1, q_2) \equiv x + \gamma q_1 + \alpha(q_2 - q_1)$ and the properties:

$$U_{q_2}^2 \equiv \alpha x_2(q_1, q_2)C_{x_2 x_2}(x_2(q_1, q_2), \beta) > 0, \quad (23)$$

$$U_{q_2 q_2}^2 \equiv \alpha^2[C_{x_2 x_2} + x_2(q_1, q_2)C_{x_2 x_2 x_2}] < 0, \quad (24)$$

and:

$$U_{q_1}^2 \equiv \begin{cases} \gamma(x + \gamma q_1)C_{x_2 x_2}((x + \gamma q_1), \beta) > 0 & \text{for } q_2 = q_1 \\ (\gamma - \alpha)(x_2(q_1, q_2))C_{x_2 x_2}(x_2(q_1, q_2), \beta) \geq 0 & q_2 > q_1 \end{cases} \quad (25)$$

$$U_{q_1 q_1}^2 \equiv \begin{cases} \gamma^2[C_{x_2 x_2} + (x + \gamma q_1)C_{x_2 x_2 x_2}] < 0 & \text{for } q_2 = q_1 \\ (\gamma - \alpha)^2[C_{x_2 x_2} + x_2(q_1, q_2)C_{x_2 x_2 x_2}] \leq 0 & q_2 > q_1 \end{cases} \quad (26)$$

Note that an increase in q_2 determines an increase of the marginal costs $C_{x_2 x_2}$, plus the reduction in the revenue obtained from the infra-marginal patients $x_2 C_{x_2 x_2 x_2}$. Condition (3) assures that the latter overweighs the former. Finally:

$$U_{q_2 \beta}^2 \equiv \alpha(x_2(q_1, q_2))C_{x_2 x_2 \beta}(x_2(q_1, q_2), \beta) > 0 \quad (27)$$

Since the value of the hospital's investment is:

$$V(q_1, x) \equiv U^1(q_1, x) + \delta \left\{ \int_0^{\beta^*} U^2(q_1, x, \beta) d\Phi(\beta) \right. \\ \left. + \int_{\beta^*}^{+\infty} \{U^2(q_2(\beta), q_1, x, \beta) - r[q_2(\beta) - q_1]\} d\Phi(\beta) \right\} \quad (28)$$

direct substitution of (19) and (22), we obtain (7) in the text.

B Proof of proposition 1

From (28), the first order condition for a maximum yields:

$$\begin{aligned}
V_{q_1}(q_1, x) &\equiv U_{q_1}^1(q_1, x) \\
&+ \delta \left\{ \int_0^{\beta^*} U_{q_1}^2(q_1, x, \beta) d\Phi(\beta) + \int_{\beta^*}^{+\infty} U_{q_1}^2(q_2(\beta), q_1, x, \beta) d\Phi(\beta) + r(1 - \Phi(\beta^*)) \right\} \\
&+ \delta \left\{ U^2(q_1, x, \beta^*) \frac{d\beta^*}{dq_1} - \{ U^2(q_2(\beta^*), q_1, x, \beta^*) - r[q_2(\beta^*) - q_1] \} \frac{d\beta^*}{dq_1} \right\} = r
\end{aligned}$$

As, by definition $U_{q_2}^2(q_1, x, \beta^*) = r$ which implies that $q_2(\beta^*) = q_1$, the above f.o.c. reduces to:

$$\begin{aligned}
V_{q_1}(q_1, x) &\equiv U_{q_1}^1(q_1, x) \tag{29} \\
&+ \delta \left\{ \int_0^{\beta^*} U_{q_1}^2(q_1, x, \beta) d\Phi(\beta) + \int_{\beta^*}^{+\infty} U_{q_1}^2(q_2(\beta), q_1, x, \beta) d\Phi(\beta) + r(1 - \Phi(\beta^*)) \right\} \\
&\equiv \theta'(q_1)[xC_x(x) - C(x)] + \delta \left\{ \int_0^{\beta^*} \gamma(x + \gamma q_1) C_{x_2 x_2}((x + \gamma q_1), \beta) d\Phi(\beta) \right. \\
&\quad \left. + \int_{\beta^*}^{+\infty} (\gamma - \alpha)(x_2(q_1, q_2(\beta))) C_{x_2 x_2}(x_2(q_1, q_2(\beta)), \beta) d\Phi(\beta) + r(1 - \Phi(\beta^*)) \right\} = r.
\end{aligned}$$

Yet, as $U_{q_2}^2(q_2(\beta), q_1, x, \beta) = r$, by (23) and (25) we may simplify (29) to:

$$V_{q_1}(q_1, x) \equiv \theta'(q_1)[xC_x(x) - C(x)] + \delta \left\{ \int_0^{\beta^*} \gamma(x + \gamma q_1) C_{x_2 x_2}((x + \gamma q_1), \beta) d\Phi(\beta) \right\} \tag{30}$$

$$\left. + \int_{\beta^*}^{+\infty} \gamma(x_2(q_1, q_2(\beta))) C_{x_2 x_2}(x_2(q_1, q_2(\beta)), \beta) d\Phi(\beta) \right\} = r.$$

Moreover, as by (26):

$$V_{q_1 q_1}(q_1, x) \equiv U_{q_1 q_1}^1(q_1, x) + \delta \left\{ \int_0^{\beta^*} U_{q_1 q_1}^2(q_1, x, \beta) d\Phi(\beta) + \int_{\beta^*}^{+\infty} U_{q_1 q_1}^2(q_2(\beta), q_1, x, \beta) d\Phi(\beta) \right\} < 0$$

there exists, for any given value of r , a unique value of q_1 satisfying equation (30). This prove the proposition.

C Proof of Lemma 2

Easy computation shows that (28) can be written as:

$$V(q_1, x) \equiv U^1(q_1, x) + \delta \int_0^{+\infty} U^2(q_1, x, \beta) d\Phi(\beta) \quad (31)$$

$$+ \delta \int_{\beta^*}^{+\infty} \{ -[U^2(q_2(\beta), q_1, x, \beta) - r q_2(\beta)] + [U^2(q_1, x, \beta) - r q_1] \} d\Phi(\beta).$$

Then, defining:

$$G(q_1, x) \equiv U^1(q_1, x) + \delta \int_0^{+\infty} U^2(q_1, x, \beta) d\Phi(\beta),$$

$$O(q_1, x) \equiv \int_{\beta^*}^{+\infty} \{ -[U^2(q_2(\beta), q_1, x, \beta) - r q_2(\beta)] + [U^2(q_1, x, \beta) - r q_1] \} d\Phi(\beta)$$

and substituting (19) and (22), we obtain the expression in the text.

D Proof of proposition 2

First of all direct inspection of (7) and (13) shows that $G_{q_1}(q_1, x) = V_{q_1}(q_1, x; \alpha = 0)$. Second, comparing (10) with (14) confirms that $V_{q_1}(q_1, x; \alpha = \gamma) = G_{q_1}(q_1, x) - \delta O_{q_1}(q_1, x)$, which implies that $q_1(\gamma = \alpha) < q_1(\alpha = 0)$. Third, as $V_{q_1}(q_1, x; \gamma = 0) < V_{q_1}(q_1, x; \alpha = \gamma)$ we get the first part of the inequality. This conclude the proof of the proposition.

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- (lix) This paper was presented at the ENGIME Workshop on “Mapping Diversity”, Leuven, May 16-17, 2002
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- (lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003
- (lxii) This paper was presented at the ENGIME Workshop on “Communication across Cultures in Multicultural Cities”, The Hague, November 7-8, 2002
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- (lxv) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications” organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
- (lxvi) This paper has been presented at the 4th BioEcon Workshop on “Economic Analysis of Policies for Biodiversity Conservation” organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL), Venice, August 28-29, 2003
- (lxvii) This paper has been presented at the international conference on “Tourism and Sustainable Economic Development – Macro and Micro Economic Issues” jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003
- (lxviii) This paper was presented at the ENGIME Workshop on “Governance and Policies in Multicultural Cities”, Rome, June 5-6, 2003
- (lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference “The Future of Climate Policy”, Cagliari, Italy, 27-28 March 2003

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